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Special Purpose Models

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SPECIAL-PURPOSE MODELS

A report entitled "Dew Survey" by Ronald Kickert has been released separately as Modelling Report Series Number 15. A model to describe strategies of annual plants in arid ecosystems by Curtis Wilcott is being prepared for publication. Special-purpose modelling activities by Mark Westoby on a termite model will be reported under separate cover. The report which follows is part of the Resource Management studies of the Desert Biome.

Model of Response of a Desert Shrub Community to Sheep Grazing

Donovan C. Wilkin

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INTRODUCTION

This is a report of progress in a Desert Biome-sponsored modelling effort covering grazing management in arid lands. The report covers work up to March, 1973, and discusses the background, theory, mathematical implementation, and further research requirements involved in this effort. The work, and this discussion, focuses almost entirely on a general form for grazing models rather than on any site-specific implementation of one; in fact, no implementation of a grazing model has been attempted as yet.

Early in 1972, a mail survey was taken of National Park and Forest Service Administrative personnel throughout the western United States. It was designed to assess the urgent and pressing problems involved in management of our arid western lands. Although the survey was limited in scope and distribution, there being less than twenty responses in all, a wide diversity of problems was mentioned. One note of unanimity, however, was striking. Each of the respondents mentioned, in one context or another, the subject of "grazing" or "overgrazing" of arid lands by domestic livestock as being a serious problem, and one that is in further need of scientific attention of some sort. It was this unanimity of response that gave the impetus to the decision to develop, if at all possible, a manager's grazing model; one that could be used as a basic management tool in the manipulation of arid grazing lands.

The primary goal of this effort has been the development of a basic form for a grazing model; a form or framework general enough to be readily modifiable to cover a broad spectrum of range types, several classes or combinations of classes of livestock, and to cover any and all seasons of grazing, whether with constant, alternate or intermittent grazing programs. The model theory and form described in this report is, hopefully, equally applicable to all the above cases.

In spite of its generality, however, the proposed model will belong to a family of models now referred to as "special purpose" models, this being in contrast to more "general purpose" whole-ecosystem models. Special purpose models are specifically designedto answer one or, at most, a very few questions of accuracy and precision. The question that this model addresses is essentially this:

> How is the growth or cover of plant species in a range plant community affected through time by the application of grazing programs?

The emphasis of the question is on the composition of the grazed plant community, but, more importantly, implied by the question is the conscious manipulation of the range plant community by the manager's application of grazing treatments. It is, as already mentioned, a manager's model. When fully developed, it should allow him to compare probable results of various combinations of management techniques, such as timing and intensity of the graze using various classes of livestock, and provide him with a reasonable assessment of the consequences of his decision as measured by the composition of the range plant community at some time in the future. It should be stated here that, given the multiplicity of management objectives foist upon land managers, the focus now is on the range animal as a manipulator of the range plant community and on the range plant community as one of the principle determiners of watershed quality, airshed quality, recreational value and so forth. No longer are public ranges managed simply to maximize meat or wool production.

At this time, it is hoped that models of this type, or future variations thereof, may substitute adequately for long-term grazing trials of the kind we have known at Pine Valley, Benmore, or Santa Rita. Hopefully, many useful comparisons of management options can be made using only long-term simulation by digital computer.

But, in addition to the proposed model's general applicability, certain other criteria can be considered equally important in order for this modelling effort to be of any significant value within a reasonable period of time: the model must rely, to a maximum degree, on existing data and data collecting techniques, and to a minimum degree on data not yet collected or on measurement techniques not fully developed; the logic involved in the model must be reasonable and understandable to the field men and managers who will be using it; the operation of the model must be a trivial matter for the user, with the computing equipment and data requirements as simple and straightforward as possible; finally, it must be inexpensive to operate, particularly important in light of agency funding at the present time.

The current proposed model form appears capable of meeting all these criteria. What follows is a description of the theory being incorporated in the model.

Theoretical Expressions

The purpose of this modelling effort has been (and is only) to describe the system adequately -- not completely. It is the author's philosophy that the best model of any system is the simplest one that will provide needed information at useful levels of accuracy and precision. With that philosophy in mind, every effort has been made to eliminate as much detail as can be, while providing a useful description of phenomena in the natural system.

A significant body of range literature now exists documenting the process of range deterioration, or, more objectively, changes in the range plant community, under domestic grazing treatments. As a general rule, those species of plants utilized most heavily by the livestock will be those damaged most severely; they operate at a competitive disadvantage in vying for the resources in the plant community. Since the most palatable plants are usually those utilized most heavily, the first approximation to a model should, hypothetically, include a general decline in the availability of the most highly desirable plants. This general decline in highly palatable species will, almost surely, be accompanied by increases in less palatable species, and in the highly opportunistic annual weeds, such as halogeton, Russian thistle, and pepperweed. Figure 1 is a graphic depiction of this process. THe author is ignoring, in this discussion, the possibility that, under lighter grazing pressure, this general pattern may not be nearly as pronounced; the responses being complicated by a possible host of overriding considerations.

Although in the short term, say five to ten years, such a simple model may be adequate, it obviously becomes less so in the long term. The decreasers all reduce to zero while the increasers climb indefinitely. Since the latter violates physical and biological principles, there must be bounds on the amount by which any given species changes -- some extreme value at which the slope of its curve either levels off, or changes sign. Based on one limited data set, it is inconclusive whether the extreme values observed represent true permanent asymptotes, or whether they are only temporary. Nonetheless, relying on successional theory, when the rate of change of the community composition becomes quite slow, as seemed to occur after 20 or 25 years of this particular experiment, the extreme values can be interpreted as new, at least semi-permanent equilibrium levels for the various species, hopefully for time periods on the order of several decades. Successional data for desert ranges are sorely needed to understand these relationships more fully. This equilibrium concept is illustrated in Figure 2. Further development of this theoretical model requires us to specify these semi-permanent equilibrium values for each of the various plant species. It is in specifying these values that we encounter a significant increase in the complexity of the model.

Although it may be trite, it must be stated that each different pasture, whether in grazed or "ungrazed" condition, possesses a different potential for the growth of its indigenous species. Where, for example, one pasture may produce mostly winterfat under a given treatment, another may produce bud sagebrush, sand dropseed, or shadscale, or any of an infinite number of combinations of these. This leads to a basic assumption used in the development of the model theory: in anticipating how a given range will respond to grazing treatment, this variation in potential must be taken into account. If, for example, in the "ungrazed" condition Pasture A contains more of a certain plant species than does Pasture B (Fig. 3), we could hypothesize that there would be proportional differences in the future composition of the two communities when subjected to identical grazing treatments. An alternative hypothesis might be that grazing favors one species over all others in both pastures, and that their ultimate compositions would become the same, in time. In this case the difference in starting composition would only affect the amount of time it took to reach this stage. This hypothesis is not favored because, in the presence of invertebrates, small mammals and birds, no range is completely "ungrazed", and the strongest evidence against producing single-species range plant communities by grazing pressure is the paucity of evidence that such a thing has ever occurred. Nonetheless, for the general purpose of the model, in order to predict how a pasture will respond to grazing treatment, the potential of the site for the growth of the individual species must be taken as a base of reference from which to make that prediction. This could be inferred by measuring the community composition under some known treatment.

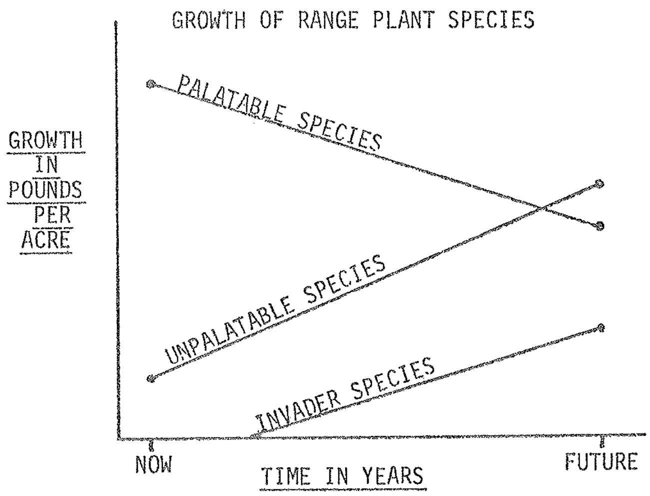

Figure 1. Hypothetical range situation where the highly palatable species, being most heavily grazed, are damaged most severely and decline in abundance. The far less palatable species and the invading weeds tend to increase in abundance. Under light grazing, this pattern may not be as distinct or as consistent as under heavy grazing, and under all treatments it is conceivable that a more heavily grazed species may, because of natural competitive advantage, increase while a less heavily grazed species decreases. This figure is meant only to depict a simple, highly stylized example under reasonably heavy grazing.

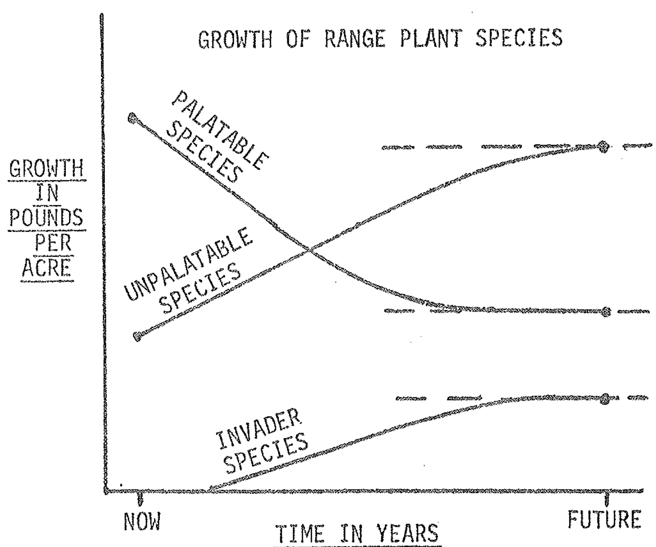

Figure 2. Hypothetical range situation as in Figure 1 with equilibrium levels for each plant group. In theory, there is a limit to the amount by which any plant species will change.

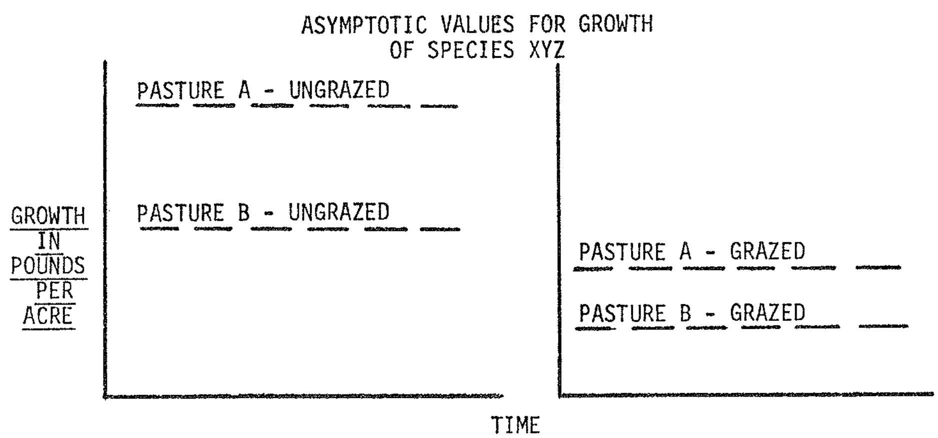

Figure 3. Each range site has a different potential for the growth of its indigenous species, regardless of the treatment. Theoretically, if a plant species is more abundant in one pasture than in another for one treatment, it might be expected to be more abundant in that pasture regardless of treatment, relatively speaking.

If the equilibrium model now being proposed is appropriate, we should be able to observe, from actual data, an indication of a trend for each species, and/or a level of equilibration for each, following the application of a new grazing treatment on a range. Figure 4 is a simulation of the yearly new growth of *Atriplex confertifolia* on a range in southern Utah, with actual growth measurements superimposed. For this site, a specific grazing treatment was applied and has been applied fairly consistently since the mid 1930's. These growth measurements were made in the fall of the various years. *Atriplex* is one of the two most predictable species for that area, being one of the two most abundant. This is only intended to show that the growth of *Atriplex* is highly variable from year to year, just as is the growth of its associated plant species. This great variability, along with relatively few data points, makes the inference of trends or of levels of stability difficult. Another fact that complicates the analysis is that, although all the plant species vary somewhat in unison, they do not do so exactly. This indicates that either the same uncontrolled variable is affecting each species differently, or that each species is responding to different uncontrolled variables, or some combination of the two.

The author felt that, before a trend analysis could be made, the variable effects of precipitation had to be eliminated from the data insofar as possible. The reason for doing so was that, for the data set being analyzed, there were seven growth measurements for the eight years, 1938 through 1945, corresponding to water years (October through September) whose mean annual precipitation was 6.29 inches, close to the long-term mean of 6.04 inches at the station; only the data for 1939 were missing. However, for the years 1946 through 1967, only four growth measurements were available, from 1947, 1957, 1958 and 1967. These four correspond to water years whose mean annual precipitation was 8.14 inches, well above the long-term mean. Without adjusting for this effect, the trend lines could be quite distorted. Admittedly, other uncontrolled variables should have been studied in connection with these growth measurements, but the only data available were those for precipitation.

Given the different root distributions for each species, different growth patterns and phenological timing, and different photosynthetic efficiencies, one might suspect that the moisture resource is partitioned among the various plant species in somewhat distinct, and hopefully predictable temporal patterns. In fact, the correlation analysis between total water year precipitation and growth of individual species showed a relatively weak relationship when compared with specific monthly precipitation patterns within the years.

Several combinations of patterns of monthly precipitation were compared with plant growth. The highest correlation coefficients arose from strings of successive monthly precipitation. Every combination of strings of monthly precipitation, from one month at a time up through 24 successive months within the 24 month period prior to measurement of plant growth were tested for correlation with plant growth. Both negative and positive correlations were observed. Table 1 summarizes the results of the correlation analysis

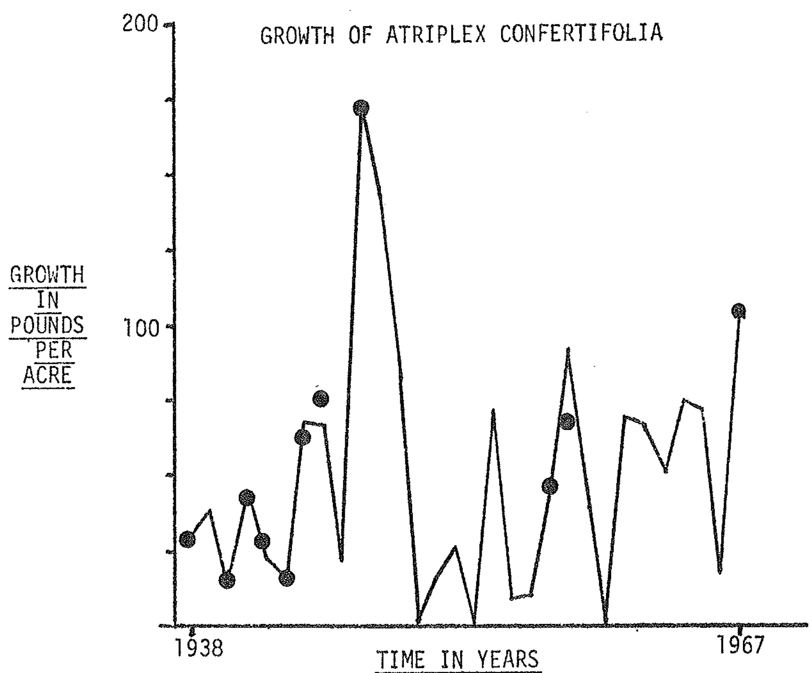

Figure 4. A simulation of the yearly new growth of *Atriplex confertifolia* in Utah's Pine Valley. Actual growth measurements are superimposed for 11 years. The extreme variability from year to year is obvious; the true trend in time is less obvious.

Table 1. Species-specific patterns of precipitation correlating most positively with the growth of range plant species

Plant Species	Period of Precipitation*	Corr. Coeff.
Atriplex confertifolia	Oct(yr-1) thru Jun (yr)	.93
Eurotia lanata	Aug(yr-1) thru Aug(yr)	.89
Artemisia spinescens	Jun(yr) thru Sep(yr)	.69
Chrysothamnus spp.	Nov(yr-1) thru Dec(yr-1)	.85
Ephedra nevadensis	Apr(yr-1)	.54
Other shrubs	Nov(yr-2)	.89
Hilaria jamesii	May(yr) thru Jul(yr)	.66
Oryzopsis hymenoides	May(yr-1) thru Jul(yr)	.91
Sporobolus spp.	Jun(yr-1) thru Jul(yr)	.93
Other grasses	May(yr-1) thru Aug(yr)	.79
Salsola kali	Jul(yr) thru Aug(yr)	.67
Sphaeralcea grossulariaefolia	Oct(yr-2) thru Aug(yr)	.89
Other forbs	Apr(yr)	.86

*Growth was measured in October of each year on a desert range in southern Utah. "yr" refers to the year in which the growth was measured.

Table 2. Species-specific patterns of precipitation correlating most negatively with the growth of range plant species

Plant Species	Period of Precipitation*	Corr. Coeff.
Atriplex confertifolia	Jan(yr) thru Feb(yr)	-.62
Eurotia lanata	Jan(yr) thru Feb(yr)	-.37
Artemisia spinescens	Oct(yr-2)	-.62
Chrysothamnus spp.	Feb(yr)	-.56
Ephedra nevadensis	Feb(yr)	-.64
Other shrubs	Jul(yr-1) thru Aug(yr-1)	-.31
Hilaria jamesii	Oct(yr-2) thru Nov(yr-2)	-.67
Oryzopsis hymenoides	Nov(yr-2) thru Mar(yr-1)	-.47
Sporobolus spp.	Jan(yr) thru Feb(yr)	-.57
Other grasses	Feb(yr-1)	-.40
Salsola kali	Oct(yr-2)	-.62
Sphaeralcea grossulariaefolia	Feb(yr-1)	-.34
Other forbs	Jun(yr-1)	-.45

* Growth was measured in October of each year on a desert range in southern Utah. "yr" refers to the year in which the growth was measured.

Next, a regression analysis was made with the correlating patterns of precipitation for any given species as the independent variables and the growth of that species as the dependent variable. There was one regression for each species or plant group being considered. Four independent variables were utilized in the predicting equation; both the positively and negatively correlating precipitation values for the current year's growth, and the same for the prior year's growth. The results indicated carryover effects of precipitation from one year to the next. A good year one year as regards precipitation seemed generally to mean somewhat more production in the following year.

With regression-developed coefficients in the equations, the history of monthly precipitation at the study site provided estimates of the growth of the various plant species on the range. This, in turn, allowed the actually observed plant growth to be somewhat normalized; adjusted to what it might be if the precipitation each year were exactly average for that area. This provided what is hopefully a more accurate indication of the growth response of the various plant species over a long period of time by reducing the variations induced by precipitation.

The revised growth curves indicated a pattern of response by the plant community to the grazing treatment that appears in reasonable accord with the hypothesized equilibrium model. Figure 5 depicts the response pattern for two of the more abundant species in the data set.

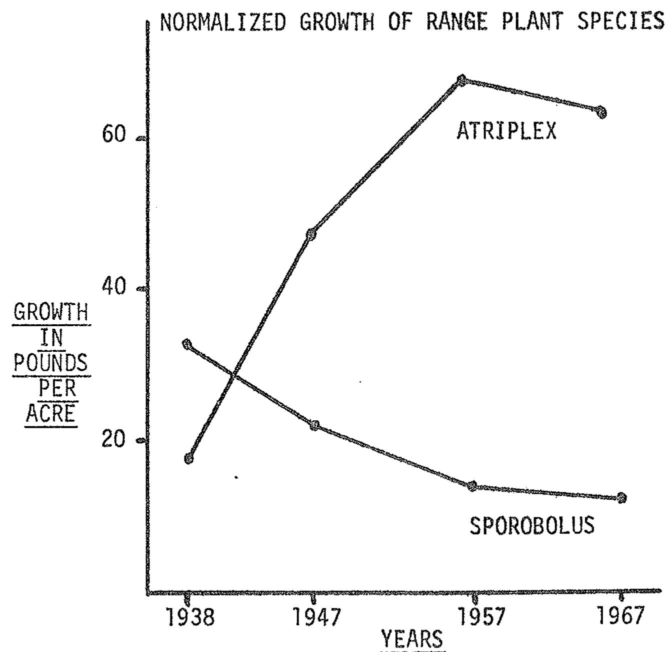

Figure 5. Actual growth values measured on the study site were normalized, insofar as possible, for the effects of precipitation. Though such curves constitute no proof of the hypothesized equilibrium needed, the author considers them supportive.

The hypothesized equilibrium model, at this point, is admittedly not supported by any rigorous statistical treatment, the preceding treatment being considered incomplete, crude, and full of the possibility of pitfalls in interpretation. Nonetheless, this analysis, in conjunction with what is known about general patterns of secondary succession in heterogeneous plant communities, and along with observations of plant communities under grazing stress in both the Desert and Grassland Biomes, indicates the equilibrium concept to be at least a reasonable hypothesis, and is a convenient basis on which to begin model development. The following, for now, are the general features of the model that will be pursued:

1. For any given plant community under a given constant grazing treatment, there is an equilibrium value for the yearly growth or cover of each plant species that will be approached at a predictable rate, and about which, under constant treatment, the growth will fluctuate as a function of short-term environmental variations (year-to-year precipitation fluctuations, for example).
2. The rate at which the equilibrium position will be approached will be generally proportional to the distance between the current value for the species and its equilibrium value, as modified by growth rates, reproductive potentials, longevity and survivorship, associated species, and so on.
3. For each different grazing treatment applied to a given community, a new group of equilibria will be dictated for the plant species therein; concomitantly, for each different community under a given grazing treatment, a different group of equilibria will be dictated.
4. The position of the equilibria will be not only a function of the grazing treatment, but of the interactions between the plant species, as well as of the potential of the site for the growth of the different species.
5. From the manager's point of view, his manipulation of stocking levels, classes of livestock, and seasons of grazing will dictate different sets of equilibria for the range plant community.

In order to more fully develop the theory being used in the model, we must consider the subject of differential utilization of the various plant species by the class or classes of livestock being grazed. The pattern of responses to grazing treatment by the various plant species should be strongly coupled to the pattern of differential utilization among them. This differential utilization alters the competitive relationships among the plants contributing to the conditions that cause some to increase in the community and some to decrease. It therefore becomes important to be able to predict, with reasonable accuracy, the differential utilization pattern for a range.

In graphic form, Figure 6 represents the situation encountered in an hypothetical single-species range community. The diagonal line represents the functional relationship between the total fractional forage removal and the fractional utilization of the single plant species. In this hypothetical situation, since forage from the single species is identical with total forage, there is a one-to-one linear relationship. This relationship holds without respect to the palatability of the plant species. If the animal eats, he must consume that species.

Figure 7 applies the same concept to a two-species range plant community. In this instance, species A constitutes 50% of the plant community, and species B the other 50%. Here, species A is more palatable (or more easily available) to the grazing animal than is species B. Now, for each plant species, a curvilinear relationship can be inferred between the amount of total forage removed and the utilization of each individual species. The curve has been labeled ".5" in each case to represent the condition that each plant species makes up 50% of the total available forage. The diagonal straight line has been left on each chart labeled "1.0" to provide the former point of reference. We are now in a position to make useful estimates of the utilization of each of these two hypothetical species, whatever their relative proportions in the plant community, all other things being equal.

We could, for instance, very roughly project the utilization for plant species A if it constituted 60% of the available forage. To wit: the ".6" curve probably lies somewhere between the ".5" curve and the "1.0" line. Conversely, for species B, since it now constitutes only 40% of available forage, its new curve probably lies below the ".5" curve. We could generalize this pattern by stating that the larger the proportion either plant species is of the total forage, the closer its utilization graph resembles the straight diagonal relationship between total forage removal and species utilization; on the other hand, the smaller proportion either is of the total forage, the further its curve lies from the straight diagonal relationship. Three other constraints help locate the position and shape of the curves. First, in all cases the curves must begin at the lower left hand corner on the graph, and must end at the upper right hand corner. Second, no curve may go above the top line, nor fall below the bottom line. Third, no part of any of the curves may have a slope less than zero. Thus, knowing the composition of the range plant community, what animal is grazing, and what percentage of the total forage is being removed, we hope to be able to make useful estimates of the fractional utilization of each individual species.

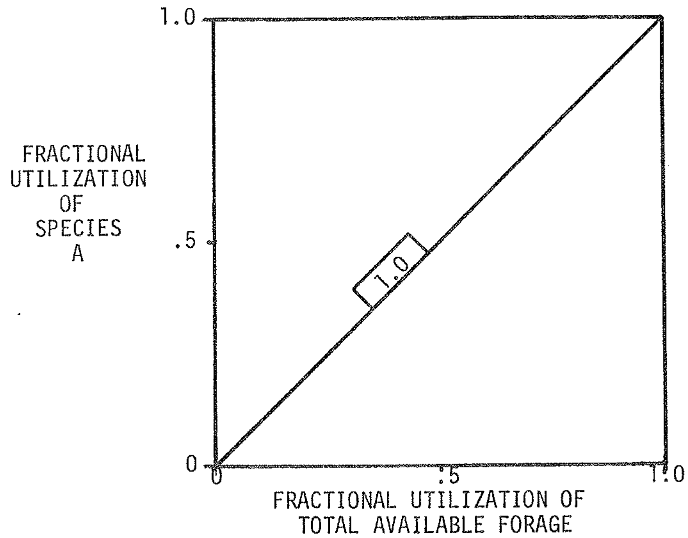

Figure 6. Hypothetical single-species range plant community. If 50% of the total available forage is taken, 50% of species A will be utilized, since that is all there is to utilize.

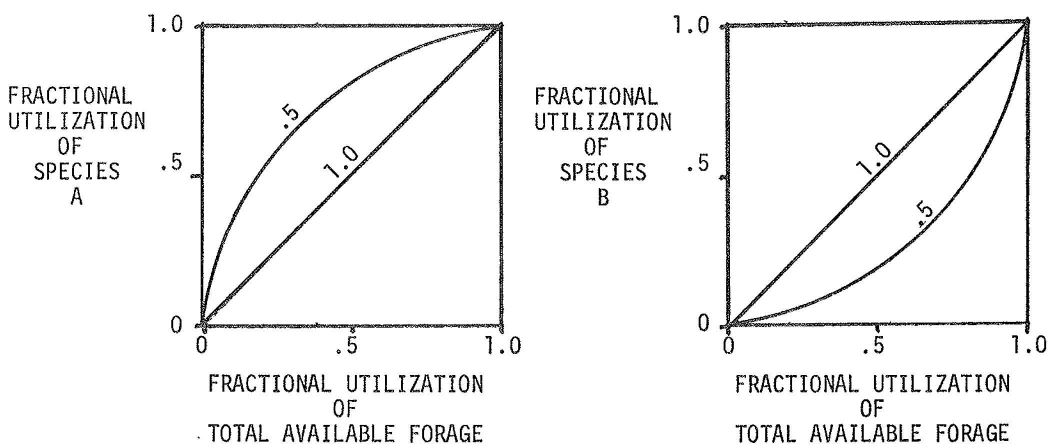

Figure 7. Hypothetical two-species range plant community. In this case, species A is preferred over species B by the grazing animal. Thus, when each species constitutes 50% of the available forage, more of species A will be taken than of species B. If species A becomes more abundant than 50%, its new utilization curve probably falls somewhere between the curve labelled ".5" and the line labelled "1.0".

It is recognized that other factors may influence palatability, or utilization as an indicator of palatability, among the plant species. Different plants in different phenological stages will probably have different palatabilities. It is also reported that differences from year to year in palatability of various species can be observed, related either to growing conditions, or to precipitation patterns during the grazing season. Modifying the predicting scheme to accomodate these relationships will, however, be a simple matter once data are available.

The scheme of predicting utilization, to this point, has been discussed from the standpoint of one specific grazing animal. Each different species of grazing animal utilizes the forage somewhat differently. Once the pattern of differential utilization is known for each animal species by itself, it should then become possible to combine these functions in some way to simulate utilization by multiple classes of livestock, in various ratios.

The ultimate goal of this utilization analysis is to assess the relative amount of damage occurring for each plant species present on the range. With this information, changes in the relative abundance of the plant species should be easier to understand. A full discussion of the technique for predicting utilization will be presented in subsequent reports.

In summary, the model is being designed to operate on the basic premise that, when the grazing treatment is changed, the composition of the plant community tends to change. It is assumed that the cover or production values for the plant species move from one equilibrium to some other, if given enough time. The relative proportions of these equilibria are considered a function of the potential of the site for the growth of each plant species, the response of individual plant species to damage by grazing, and short-term environment variations, particularly those of precipitation.

Mathematical Expressions

The general process involved in the mathematical development of the model is, at present, to search for and compare various mathematical equation <u>forms</u> that best express the processes herein described. The principle criterion by which the equation forms are judged is the faithfulness of the behavior of each function to what is known to be or considered to be biological "reality". When function forms are found that are considered useful, they will be fit to the data available and parameters will be developed. The process of mathematical expression of the model, along with the results thereof, will be discussed in subsequent reports.

Input and Operation Requirements

As presently conceived, the model will be operated from an interactive computer terminal. An early version of the model was set up to be so operated and, because of the relatively simple input requirements, it appears to be a satisfactory and interesting way of operating the model.

Because each model implementation will be for a specific site, each will require local precipitation data. These will be included intrinsically within the model itself, and will not be required from the operator. Site-specific implementation makes the operation of the model far easier than if weather inputs are required. This argument can be extended by virtue of the possibility of having to include, at some future time, other important site characteristics such as slope or aspect, soil properties, and so on. If such information can be built into the model program, the operator's job is simplified.

Operation of the model will be simple. Once the operator logs onto the system and identifies himself, he then issues the command (appropriate to the system being used) to the effect that he wishes to run the grazing model for a particular site. After issuing the run command, a brief description of the system being simulated appears on the screen. Then, one by one, questions appear on the screen to which the operator responds. A few <u>representative</u> types of questions are listed below for example.

-WHAT YEAR DO YOU WISH TO BEGIN THE SIMULATION? (question appears of the screen)
-1973 (operator answers)
-WHAT YEAR DO YOU WISH THE SIMULATION TO END?
-1998 (operator answers)
(For the following questions the operator answer will be eliminated. During an actual run, however, no question would appear until the previous question had been answered).
-WHEN WAS THE VEGETATION LAST SAMPLED?
-ARE THE DATA IN COVER OR WEIGHT?
-HOW MANY POUNDS (WHAT WAS THE PERCENT OF COVER) OF SPECIES A?
-DITTO (other plant species)
-WHAT IS THE APPROXIMATE PERCENT OF TOTAL FORAGE REMOVAL EACH YEAR?
-WHAT PROPORTION OF THE REMOVAL HAS BEEN ACCOMPLISHED BY SHEEP?
-DURING WHAT SEASON?
-WHAT PROPORTION OF THE REMOVAL HAS BEEN ACCOMPLISHED BY CATTLE?
-DURING WHAT SEASON
-DITTO(other classes of livestock)
-FOR THE SIMULATION PERIOD, WHAT PROPORTION OF TOTAL FORAGE REMOVAL WILL OCCUR?
-WHAT PROPORTION OF REMOVAL WILL BE BY SHEEP?
-WHEN?
-DITTO (other classes of stock)

With information of this sort, the model then computes, as of the final year of simulation, the composition of the range plant community. Based on earlier versions of the model, something on the order of two to five minutes of the operator's time will be required to furnish the necessary input data. The model is expected to be small enough so that essentially no delay is encountered between the final datum input and the presentation of the computed output on the screen.

Output

The output will also be quite simple. Since nobody knows whether the final year of simulation will be very wet, very dry or something intermediate, the program computes the possible range of values of cover or growth for each plant species. Table 3 is an example of what the operator will have printed as output on his terminal screen.

Table 3. Facsimile of computer output appearing on the operator's screen

Growth of Range Plant Species as of Year 2000
in Plotkin Valley -- Plot 376

Cattle -- 15% -- Winter
Sheep -- 15% -- Winter

Plant Species	Driest Year	Median Year	Mean Year	Wettest Year
Atriplex confertifolia	35	70	80	235
Eurotia lanata	10	18	26	94
Artemisia spinescens	0	0	0	0
Chrysothamnus spp.	0	1	1	1
Ephedra nevadensis	0	0	0	0
Other shrubs	3	11	16	43
Hilaria jamesii	14	21	25	86
Oryzopsis hymenoides	3	6	7	25
Sporobolus spp.	31	63	74	188
Other grasses	5	9	11	31
Salsola kali	0	6	20	88
Sphaeralcea grossulariaefolia	0	2	4	21
Other forbs	0	2	3	16
Total vegetation	101	209	267	838

Research Needs

At present, adequate data to support implementations of this model are scarce. Nonetheless, the kinds of data needed are reasonably easy to obtain, technically speaking; they are of the nature of simple observation or involve straightforward experimental methods using techniques already well-in-hand by desert ecologists. For some sites, they may already be available.

In general, the research needs to support implementations of this model are as follows:

1. Continuing work to improve the prediction of differential forage utilization by various single classes of livestock.
2. Continuing work to improve the prediction of differential forage utilization by multiple classes of livestock.
3. Continuing work to deduce the effects of utilization by livestock on subsequent growth and vigor of the various individual range plant species.
4. Continuing work to deduce the effects of utilization by livestock on the reproductive processes of the various individual range plant species.
5. Empirical observations of different range sites under controlled grazing treatments covering a range of classes of livestock during different times of the year, with particular emphasis on providing matched areas of grazed and ungrazed sites for comparison of effects.
6. Work to begin understanding patterns of secondary succession of desert ranges, their causes, and their rates.

Future Work

Since the implementation of this model theory will soon be paced by the availability of site-specific data, these data and research needs will be made known to scientists involved in arid lands study. A search will begin, both in the United States and outside, for any possible existing data sets sufficient to allow implementation.

Continuing along lines of conjecture, the author, in working out the theory to be used in this model, believes that the same general concepts can apply to a more general "perturbation" model, as opposed to a strictly "grazing" model. In essence, if the kinds of perturbations to be expected in our desert regions can be lumped more or less into "kinds" of perturbation, it would seem that, in a realistic sense, there are relatively few "kinds" of perturbation we would expect to have significant impact... selective defoliation, obviously, would be one "kind" of perturbation ... soil surface disturbance (traffic and trampling) might be another "kind" ... complete sacrificial use such as for housing, a motorcycle race course, or a dump, might be another "kind" of

It is possible that there are few enough of these anticipated to be of significance in the future that we could study each "kind" of perturbation to determine a general pattern of response by the desert plant community for each. If such patterns can be elucidated, and I am hopeful they can be, we can then make a wide variety of general predictions, in the nature of environmental impact statements for various uses of the desert, by anticipating the severity of each type of disturbance associated with those uses. The author considers this to be a promising and rewarding direction for future Biome research and modelling efforts.